New Vision of the Saturnian System in the Context of a Highly Dissipative Saturn – Editorial

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Over the past fifteen years, our understanding of the Saturnian system has undergone a profound transformation. Long considered a relatively stable and slowly evolving system, Saturn and its moons are now recognized as a highly dynamic environment shaped by unexpectedly strong tidal dissipation within the planet. This paradigm shift has far-reaching consequences, from the orbital evolution of the satellites to their origin and long-term history.

A key breakthrough came from the ability to measure the current orbital evolution of Saturn's moons with unprecedented precision. These observations revealed that tidal interactions within Saturn are far more efficient than previously thought, driving rapid outward migration of the satellites. This result opens new possibilities for interpreting long-standing puzzles, such as the intense internal activity of Enceladus, but also challenges classical assumptions about the age and formation of the Saturnian moons and rings.

The wealth of high-quality data provided by the Cassini spacecraft during its 13 years-long mission at Saturn has played a central role in this transformation. Long-term, in-situ observations have enabled a detailed reconstruction of the dynamical evolution of the system, while also highlighting inconsistencies with traditional tidal models. In response, new theoretical frameworks have emerged, in which tidal dissipation is governed by complex interactions between the satellites and the evolving internal structure of Saturn. These mechanisms naturally account for the observed diversity of orbital behaviors and rapid migration rates.

Beyond their dynamical implications, these results provide a unique window into the deep interior of Saturn. The efficiency and apparent frequency dependence of tidal dissipation suggest that internal processes (such as stratification, layered convection, or resonant oscillation modes) play a central role in shaping the system's evolution. In this sense, the orbital architecture of the moons becomes a diagnostic tool, offering indirect but powerful constraints enlightening the physical properties and long-term evolution of the planet itself.

At the same time, the current orbital state of the Saturnian system (marked by numerous resonances and ongoing dynamical interactions) points to a history of significant evolution. These constraints suggest that some moons may be much younger than previously assumed, raising fundamental questions about their origin. In this context, alternative formation scenarios have been developed. In one class of models, moons form from the spreading of Saturn's rings and subsequently migrate outward under the influence of strong tidal forces. In another, large tidal expansions may lead to resonance crossings, triggering collisions, satellite re-accretion, and possibly the formation of rings. Together, these scenarios highlight a coupled evolution of rings and satellites, providing a coherent framework that naturally explains several key features of the system.

Taken together, these advances outline a new, consistent picture of the Saturnian system, in which rings, moons, and planetary interiors are intimately connected through coupled dynamical and physical processes. This emerging vision not only reshapes our understanding of Saturn, but also provides a broader framework for interpreting the origin and evolution of giant planet systems, both within and beyond our solar system.

More broadly, the Saturnian system now appears as a natural laboratory for studying tidal processes under extreme conditions. The lessons learned here are likely to guide our understanding of a wide range of astrophysical systems, from exoplanetary systems hosting close-in satellites or planets, to the evolution of giant planets' internal structure. Future observational efforts and potential new space missions will be essential to collect better data necessary for testing and refining this new paradigm.

This collection originates from an International Space Science Institute (ISSI) workshop entitled "New Vision of the Saturnian System in the Context of a Highly Dissipative Saturn", which brought together experts in planetary dynamics, interior physics, ring science, and satellite geophysics. The workshop provided the opportunity to confront recent observational constraints with emerging theoretical models, with a particular focus on the implications of strong tidal dissipation for the coupled evolution of Saturn, its rings, and its satellites. These discussions led to the identification of key open questions and helped structure the contributions presented in this volume. The articles are organized around the major themes addressed during the workshop, providing complementary perspectives on the origin, evolution, and present-day dynamics of the Saturnian system. Together, they offer a coherent synthesis of recent progress while outlining the main challenges that remain to be addressed. The Saturnian system thus stands as a cornerstone for future studies of planetary dynamics and evolution.

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